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Research & Development Center

Report No. CG-D-04-13

AAPSilver System Performance Validation

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16. Abstract (MAXIMUM 200 WORDS)

The Visual Navigation Division (CG-NAV-1) requested that the Coast Guard Research and Development Center (RDC) examine the accuracy of the new AAPSilver software in calculating the geographic positions (latitude and longitude) of bearing and range offsets from reference locations. The USCG R&D Center tested the software by comparing the AAPSilver output to independently calculated results that were calculated by an algorithm obtained from the National Geodetic Survey. Combinations of test points and offsets were input to AAPSilver, which provided latitude-longitude pairs as outputs. These coordinates were then compared to calculations from the National Geodetic Survey's FORWARD program, which served as the reference for the assessment of AAPSilver.

Offset positions agreed to within 8 cm in range and agreed exactly in bearing to the calculated reference measurements. These differences may be compared to uncertainties associated with the use of Differential Global Positioning System receivers used to position Coast Guard ATON vessels when the adequacy of the AAPSilver software is considered for distribution throughout the Coast Guard ATON fleet.

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EXECUTIVE SUMMARY

The Coast Guard uses a software package called the Automated Aid Positioning System (AAPS) to maintain and manage its Aids to Navigation (ATON) system. The Coast Guard will be updating AAPS to a new version called AAPSilver. The software update includes changes that could potentially affect its calculations of the geographic coordinates of ATON assets. The Visual Navigation Division (CG-NAV-1) has requested that the Coast Guard Research and Development Center (RDC) examine the performance of the new AAPSilver software in calculating the geographic positions (latitude and longitude) of bearing and range offsets from reference locations.

The USCG R&D Center tested the software by comparing the AAPSilver output to independently calculated results that were calculated by an algorithm obtained from the National Geodetic Survey. Combinations of test points and offsets were generated for test points in each of the four quadrants of the globe to test the accuracy of the system in the Coast Guard's Areas of responsibility. We created eight random offset range and bearing combinations for each test point. These range-bearing pairs were input to AAPSilver which provided latitude-longitude pairs as outputs. These coordinates were then compared to calculations from the National Geodetic Survey's FORWARD program, which served as the reference for the assessment of AAPSilver.

Offset positions agreed to within 8 cm in range and agreed exactly in bearing to the calculated reference measurements. These differences may be compared to uncertainties associated with the use of Differential Global Positioning System receivers used to position Coast Guard ATON vessels when the adequacy of the AAPSilver software is considered for distribution throughout the Coast Guard ATON fleet.

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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AAPS	Automated Aid Positioning System
AP	Assigned Position
ATON	Aids to Navigation
BPP	Buoy Port Position
CGDN	Coast Guard Data Network
CG-NAV-1	Coast Guard Headquarters Visual Navigation Division
GPS	Global Positioning System
I-ATONIS	Integrated Aids to Navigation Information System
NMEA	National Marine Electronics Association
OSC	Coast Guard Operations Systems Center, Martinsburg, WV
RDC	Research and Development Center

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1 BACKGROUND

The Coast Guard is responsible for maintaining a network of fixed and floating aids to navigation to support the nation's marine transportation system. These aids must be maintained and physically positioned, as necessary, in order to mark the boundaries of our navigable waters. The Coast Guard manages information on more than 100,000 federal and private ATONs using the Integrated Aids to Navigation Information System (I-ATONIS). I-ATONIS is a distributed and centralized database system that is maintained by the Operations Systems Center (OSC), located in Martinsburg, WV, which holds the I-ATONIS Database for the entire Coast Guard. Coast Guard units and District offices access the central I-ATONIS database using the Coast Guard Data Network (CGDN+) to track and schedule maintenance, in order to keep the nationwide ATON system operating properly.

Field users use the Automated Aid Positioning System (AAPS) software interface to document the status of the system and to manage and maintain the ATON system. The information exchanged through the AAPS interface includes:

- Physical configuration and status of the aid
- Location and location accuracy
- Light beacon and electrical power system characteristics
- Mooring system details
- The history of ATON maintenance

Coast Guard units or contractors conduct periodic visits to each ATON in the system. The position of each floating buoy is checked each time it is visited, and a determination is made as to whether the buoy is on or off station, in accordance with standards contained in the Aids to Navigation Manual – Positioning, COMDTINST M16500.1 (series). The USCG publishes the positions of floating and fixed aids to navigation in the 8 volumes of the Light List.

The Visual Navigation Division (CG-NAV-1) has updated the AAPS software to a new version called AAPSilver. The software update includes changes that could potentially affect its calculations of the geographic coordinates of ATON assets. CG-NAV-1 has asked the Coast Guard Research and Development Center (RDC) to examine the accuracy of the new AAPSilver software in calculating geographic positions (latitude and longitude) of bearing and range offsets from reference vessel locations.

This report documents a test of a function, in which a Coast Guard ATON vessel would be placing an ATON in an Assigned Position (AP). APs are conveyed to mariners through the Light Lists and other automated processes that produce charts and related hydrographic products. It is therefore of great importance to ensure that buoy and beacon positions meet Coast Guard positioning standards. The Coast Guard vessel handles and positions the ATON from a buoy port on the vessel whose position, the buoy port position (BPP), is calculated from a GPS fix, the ship's heading, and the position offset of the buoy port relative to the GPS antenna. AAPSilver provides ranges and bearings from the BPP to the AP, to assist the vessel in converging on the AP to within Coast Guard positioning tolerances.

2 PROCEDURE

The AAPSilver test focused on comparing calculations made by AAPSilver with those made by a reference software application. Eight APs were placed around each BPP, with two APs in each quadrant relative to the BPP (Figure 1).

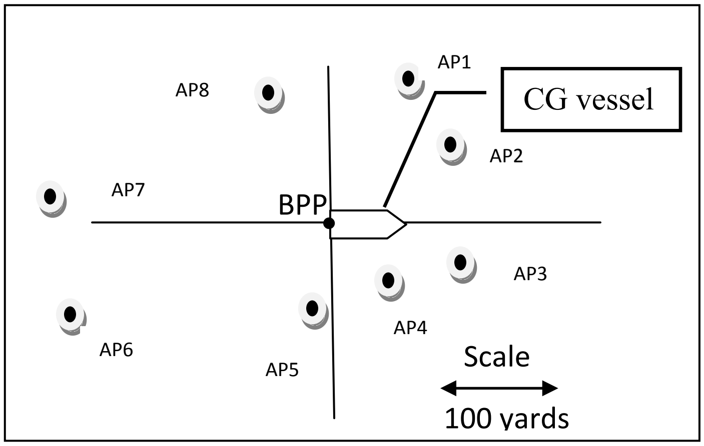

Figure 1. Assigned point and buoy port configuration.

Comparisons were made at four BPPs that were placed around the globe. The positions chosen for the four BPPs (Table 1) mirrored those of an earlier RDC study, to provide calculations that were comparable with earlier versions of AAPS.

Table 1. Vessel buoy port position (BPP) assigned positions used for this study.

Vessel Assigned Position (AP)	Latitude (dd mm ss H)	Longitude (ddd mm ss H)
Alpha	41 00 00 N	072 00 00 W
Bravo	13 00 00 N	144 00 00 W
Charlie	60 00 00 S	087 00 00 E
Delta	10 00 00 S	170 00 00 E

The AP offsets (Table 2) were also those used in the 1999 evaluation, to permit a comparison of results, if desired. The National Geodetic Survey's FORWARD application was used to calculate the geodetic position (latitude and longitude in degrees, minutes, and seconds) of each AP from each BPP based on the AP's azimuth and range. FORWARD, which is run on-line, uses a reference position (i.e. BPP), a range, and a bearing as inputs, and calculates the resulting latitude and longitude (AP) as outputs. FORWARD was used to generate eight latitude/longitude APs at various ranges and bearings ("offsets") around each BPP. The same set of offsets was used at each of the four BPPs.

During normal use, AAPSilver accepts an output string from the ship's GPA receiver to determine the ship's BPP. The receiver's position is contained as a NMEA $GPGGA message. For this test, AAPSilver

Table 2. Target position offsets used for each assigned position.

Test Point ID	Range (yds)	Azimuth ° True
AP1	100	30
AP2	75	59
AP3	60	110
AP4	20	157
AP5	87	182
AP6	300	241
AP7	640	294
AP8	31	345

was modified by the technical support contractor at the Coast Guard Operations Systems Center (OSC), Martinsburg, WV to permit the manual insertion of each BPP in a synthetic $GPGGA string. The AP positions were input using the 'New Federal" button in the AAPSilver ATON page. The Range and Bearing calculated by AAPS were recorded and compared to the "True" Range and Bearing value used for the FORWARD calculation for each BPP.

The procedure for the test was as follows:

1) A spreadsheet was assembled for the input and output data that contained a separate worksheet for BPPs ALPHA through DELTA.
2) The FORWARD program was run to create the AP coordinates for each BPP. Eight APs were entered on each worksheet, and formatted in the spreadsheet for input to AAPSILVER. The FORWARD inputs are the BPP and the Assigned Point offset (Range and Azimuth). The output of FORWARD is the resulting latitude and longitude, which are then formatted in the spreadsheet for input to AAPSilver.
3) AAPSilver was started. In the settings menu, right-click on the screen to enable manual $GPGGA entry, and paste the $GPGGA string for the first BPP. This tells the software that the vessel is at the BPP. In the "Vessel" screen, "Jump Kit" was selected as the GPS device. This sets the GPS antenna and BPP positions to the same location (i.e. zero offset).
4) Enter the ATON screen, select the search icon, and the Search Aids screen will come up. Select the "New Federal" icon to identify a new federal aid. Paste in the AP name and position from the worksheet file. Select "Add", and then highlight the icon in the upper left corner. This step simulates the position of the aid at the AP.
5) Go to the "Positioning" screen. The vessel position will be displayed in the lower left corner. The range and bearing to the AP will be displayed in the upper right corner: that range and bearing are compared to the values input to the FORWARD Program in step 2.

3 RESULTS

An initial comparison for the eight APs at the four BPPs: Alpha, Bravo, Charlie, and Delta, is presented in the top eight rows of Tables 3 through 6. The range and bearing offsets calculated by AAPSilver were typically identical to those input into FORWARD. The observed differences ranged from 1-4 cm. The differences were examined, and in most cases could be attributed to roundoff in the seconds field of the latitude or longitude. In other words, the difference was typically due to a difference in the fourth digit in seconds of latitude or longitude.

The largest differences between the AAPSilver and FORWARD calculations were observed at BPP Charlie, and appeared to scale with range. In addition, we decided also to conduct a brief exercise of the performance of the AAPSilver software at cardinal points of the compass. A fifth BPP, Echo, was created to exercise AAPSilver at longer ranges and at the 90° and 180° bearings, and at ranges out to 2000 yards. The initial test produced range error disparity increased at an approximately linear rate, to a maximum of 0.08 yards at 2000 yards. A more significant result was that the bearing from BPP to Assigned Points at the 180° bearing was in error by 180°, so that the bearing reported by AAPSilver was 0° instead of 180° (not shown in Table 7).

This problem was reported to the sponsor and the contractor at OSC, Martinsburg. The contractor traced the problem to a bug in the software that would only occur in South latitudes and West longitudes. The contractor corrected the problem, and the BPP Echo cases were re-run. The results, shown in Table 7, were now consistent with those for the other BPPs: Range errors were on the order of a few centimeters, and increased to a maximum difference of 8 cm at 2000 yards. The bearing error problem was corrected.

Another set of runs was also conducted for BPPs Alpha, Bravo, and Delta. The results are in Tables 3, 4, and 6 as Assigned Points 9 and greater (> AP9). These runs confirmed to our satisfaction that the bearing error had been rectified. It also confirmed that the error that had once existed in the South and West quadrant of the globe did not exist in the other quadrants.

Table 3. Comparison between FORWARD and AAPSilver calculations for BPP Alpha at 41° N 72° W.

Reference Position (BPP)		Assigned Point Offset			Assigned Point ID	AAPSilver INPUT:		AAPSilver Calculated Offset	
Latitude	Longitude	Range		Azimuth		AP Latitude	AP Longitude	Range	Bearing
Hdd	Hdd	**yds**	m	**° True**		dd-mm-ss.ssssH	ddd-mm-ss.ssssH	**yds**	**T**
N41	W72	**100**	91.44	**30**	ALPHA AP1	41-00-02.5671N	071-59-58.0437W	**100**	**30.00**
N41	W72	**75**	68.58	**59**	ALPHA AP2	41-00-01.1450N	071-59-57.4847W	**75**	**59.00**
N41	W72	**60**	54.864	**110**	ALPHA AP3	40-59-59.3917N	071-59-57.7940W	**60**	**110.00**
N41	W72	**20**	18.288	**157**	ALPHA AP4	40-59-59.4543N	071-59-59.6943W	**20**	**157.00**
N41	W72	**87**	79.5528	**182**	ALPHA AP5	40-59-57.4227N	072-00-00.1188W	**87**	**182.00**
N41	W72	**300**	274.32	**241**	ALPHA AP6	40-59-55.6887N	072-00-10.2658W*	**300.01**	**241.00**
N41	W72	**640**	585.216	**294**	ALPHA AP7	41-00-07.7155N	072-00-22.8763W‡	**640.01**	**294.00**
N41	W72	**31**	28.3464	**345**	ALPHA AP8	41-00-00.8876N	072-00-00.3139W	**31**	**345.00**
N41	W72	**1000**	914.4	**0**	ALPHA AP9	41-00-29.6418N	072-00-00.0000W	**999.98**	**0.00**
N41	W72	**1000**	914.4	**90**	ALPHA AP10	40-59-59.9982N	071-59-20.8744W	**1000.03**	**90.00**
N41	W72	**1000**	914.4	**180**	ALPHA AP11	40-59-30.3582N	072-00-00.0000W	**999.98**	**180.00**
N41	W72	**1000**	914.4	**270**	ALPHA AP12	40-59-59.9982N	072-00-39.1256W	**1000.03**	**270.00**
N41	W72	**0**	0	**0**	ALPHA AP13	41-00-00.0000N	072-00-00.0000W	**0**	**90.00**

* Changing this value to 072°-00'-10.2657"W drops the range to 300.00 yards

‡ Changing this value to 072°-00'-22.8763" drops the range to 640.00 yards

Table 4. Comparison between FORWARD and AAPSilver calculations for BPP Bravo at 13° N 144° E.

Reference Position (BPP)		Assigned Point Offset			Assigned Point ID	AAPSilver INPUT:		AAPSilver Calculated Offset	
Latitude	Longitude	Range		Azimuth		AP Latitude	AP Longitude	Range	Bearing
Hdd	Hdd	**yds**	m	**° True**		dd-mm-ss.ssssH	ddd-mm-ss.ssssH	**yds**	**T**
N13	E144	**100**	91.44	**30**	**BRAVO AP1**	13-00-02.5769N	144-00-01.5172E	**100**	**30.00**
N13	E144	**75**	68.58	**59**	**BRAVO AP2**	13-00-01.1494N	144-00-01.9507E	**75**	**59.00**
N13	E144	**60**	54.864	**110**	**BRAVO AP3**	12-59-59.3894N	144-00-01.7108E	**60**	**110.00**
N13	E144	**20**	18.288	**157**	**BRAVO AP4**	12-59-59.4522N	144-00-00.2371E	**20**	**157.00**
N13	E144	**87**	79.5528	**182**	**BRAVO AP5**	12-59-57.4129N	143-59-59.9079E	**86.99***	**182.00**
N13	E144	**300**	274.32	**241**	**BRAVO AP6**	12-59-55.6723N	143-59-52.0382E	**300**	**241.00**
N13	E144	**640**	585.216	**294**	**BRAVO AP7**	13-00-07.7455N	143-59-42.2588E	**640**	**294.00**
N13	E144	**31**	28.3464	**345**	**BRAVO AP8**	13-00-00.8910N	143-59-59.7565E	**31**	**345.00**
N13	E144	**1000**	914.4	**0**	**BRAVO AP9**	13-00-29.7553N	144-00-00.0000E	**999.94**	**0.00**
N13	E144	**1000**	914.4	**90**	**BRAVO AP10**	12-59-59.9995N	144-00-30.3438E	**1000.01**	**90.00**
N13	E144	**1000**	914.4	**180**	**BRAVO AP11**	12-59-30.2447N	144-00-00.0000E	**999.94**	**180.00**
N13	E144	**1000**	914.4	**270**	**BRAVO AP12**	12-59-59.9995N	143-59-29.6562E	**1000.01**	**270.00**

* - With latitude rounded down to 12°-59'-57.4128"N, the range calculated by AAPSilver is 87.0 yards.

Table 5. Comparison between FORWARD and AAPSilver calculations for BPP Charlie at 60° S 87° W.

Reference Position (BPP)		Assigned Point Offset			Assigned Point ID	AAPSilver INPUT:		AAPSilver Calculated Offset	
Latitude	Longitude	Range		Azimuth		AP Latitude	AP Longitude	Range	Bearing
Hdd	Hdd	**yds**	m	**° True**		dd-mm-ss.ssssH	ddd-mm-ss.ssssH	**yds**	**T**
S60	W87	**100**	91.44	**30**	**CHARLIE AP1**	59-59-57.4412S	086-59-57.0504W	**100**	**30.00**
S60	W87	**75**	68.58	**59**	**CHARLIE AP2**	59-59-58.8587S	086-59-56.2075W	**75**	**59.00**
S60	W87	**60**	54.864	**110**	**CHARLIE AP3**	60-00-00.6063S	086-59-56.6738W	**60**	**110.00**
S60	W87	**20**	18.288	**157**	**CHARLIE AP4**	60-00-00.5439S	086-59-59.5390W	**20**	**157.00**
S60	W87	**87**	79.5528	**182**	**CHARLIE AP5**	60-00-02.5691S*	087-00-00.1791W	**87.01**	**182.00**
S60	W87	**300**	274.32	**241**	**CHARLIE AP6**	60-00-04.2971S	087-00-15.4796W	**300.01**	**241.00**
S60	W87	**640**	585.216	**294**	**CHARLIE AP7**	59-59-52.3075S	087-00-34.4895W	**640.04**	**294.00**
S60	W87	**31**	28.3464	**345**	**CHARLIE AP8**	59-59-59.1153S	087-00-00.4733W	**31**	**345.00**

* - When this position was rounded down to 60°-00'-02.5690"S, the range dropped to 87.00 yards

Table 6. Comparison between FORWARD and AAPSilver calculations for BPP Delta at 10° S 170° E.

Reference Position (BPP)		**Assigned Point Offset**			**Assigned Point ID**	**AAPSilver INPUT:**		**AAPSilver Calculated Offset**	
Latitude	Longitude	Range		Azimuth		AP Latitude	AP Longitude	Range	Bearing
Hdd	Hdd	**yds**	m	**° True**		dd-mm-ss.ssssH	ddd-mm-ss.ssssH	**yds**	**T**
S10	E170	**100**	91.44	**30**	**DELTA AP1**	09-59-57.4226S	170-00-01.5012E	**100**	**30.00**
S10	E170	**75**	68.58	**59**	**DELTA AP2**	09-59-58.8504S	170-00-01.9302E	**75**	**59.00**
S10	E170	**60**	54.864	**110**	**DELTA AP3**	10-00-00.6107S	170-00-01.6928E	**60**	**110.00**
S10	E170	**20**	18.288	**157**	**DELTA AP4**	10-00-00.5479S	170-00-00.2346E	**20**	**157.00**
S10	E170	**87**	79.5528	**182**	**DELTA AP5**	10-00-02.5877S	169-59-59.9088E	**87**	**182.00**
S10	E170	**300**	274.32	**241**	**DELTA AP6**	10-00-04.3286S	169-59-52.1220E	**300**	**241.00**
S10	E170	**640**	585.216	**294**	**DELTA AP7**	09-59-52.2526S	169-59-42.4459E	**640**	**294.00**
S10	E170	**31**	28.3464	**345**	**DELTA AP8**	09-59-59.1088S	169-59-59.7591E	**31**	**345.00**
S10	E170	**1000**	914.4	**0**	**DELTA AP9**	09-59-30.2386S	170-00-00.0000E	**999.94**	**0.00**
S10	E170	**1000**	914.4	**90**	**DELTA AP10**	09-59-59.9996S	170-00-30.0243E	**1000.01**	**90.00**
S10	E170	**1000**	914.4	**180**	**DELTA AP11**	10-00-29.7614S	170-00-00.0000E	**999.94**	**180.00**
S10	E170	**1000**	914.4	**270**	**DELTA AP12**	09-59-59.9996S	169-59-29.9758E	**1000.01**	**270.00**
S10	E170	**1000**	914.4	**360**	**DELTA AP13**	09-59-30.2386S	170-00-00.0000E	**999.94**	**0.00**

Table 7. Comparison between FORWARD and AAPSilver calculations for BPP Echo at 60° S 87° W.

Reference Position (BPP)		Assigned Point Offset			Assigned Point ID	AAPSilver INPUT:		AAPSilver Calculated Offset	
Latitude	Longitude	Range		Azimuth		AP Latitude	AP Longitude	Range	Bearing
Hdd	Hdd	**yds**	m	**° True**		dd-mm-ss.ssssH	ddd-mm-ss.ssssH	**yds**	**T**
S60	W87	**100**	91.44	**90**	**ECHO AP1**	60-00-00.0000S	086-59-54.1007W	**100**	**90.00**
S60	W87	**500**	457.2	**90**	**ECHO AP2**	60-00-00.0000S	086-59-30.5032W	**500.02**	**90.00**
S60	W87	**1000**	914.4	**90**	**ECHO AP3**	60-00-00.0000S	086-59-01.0065W	**1000.04**	**90.00**
S60	W87	**2000**	1828.8	**90**	**ECHO AP4**	60-00-00.0000S	086-58-02.0129W	**2000.08**	**90.00**
S60	W87	**100**	91.44	**180**	**ECHO AP5**	60-00-02.9547S	087-00-00.0000W	**100**	**180.00**
S60	W87	**500**	457.2	**180**	**ECHO AP6**	60-00-14.7732S	087-00-00.0000W	**500.01**	**180.00**
S60	W87	**1000**	914.4	**180**	**ECHO AP7**	60-00-29.5465S	087-00-00.0000W	**1000.02**	**180.00**
S60	W87	**2000**	1828.8	**180**	**ECHO AP8**	60-00-59.0929S	087-00-00.0000W	**2000.04**	**180.00**
S60	W87	**100**	91.44	**270**	**ECHO AP9**	60-00-00.0000S	087-00-05.8994W	**100**	**270.00**
S60	W87	**500**	457.2	**270**	**ECHO AP10**	59-59-59.9991S	087-00-29.4968W	**500.02**	**270.00**
S60	W87	**1000**	914.4	**270**	**ECHO AP11**	59-59-59.9963S	087-00-58.9936W	**1000.04**	**270.00**
S60	W87	**2000**	1828.8	**270**	**ECHO AP12**	59-59-59.9854S	087-01-57.9871W	**2000.08**	**270.00**
S60	W87	**100**	91.44	**360**	**ECHO AP13**	59-59-57.0454S	087-00-00.0000W	**100**	**0.00**
S60	W87	**500**	457.2	**360**	**ECHO AP14**	59-59-45.2268S	087-00-00.0000W	**500.01**	**0.00**
S60	W87	**1000**	914.4	**360**	**ECHO AP15**	59-59-30.4535S	087-00-00.0000W	**1000.02**	**0.00**
S60	W87	**2000**	1828.8	**360**	**ECHO AP16**	59-59-00.9070S	087-00-00.0000W	**2000.04**	**0.00**
S60	W87	**100**	91.44	**359**	**ECHO AP17**	59-59-57.0458S	087-00-00.1030W	**100**	**359.00**
S60	W87	**500**	457.2	**359**	**ECHO AP18**	59-59-45.2290S	087-00-00.5147W	**500.01**	**359.00**
S60	W87	**1000**	914.4	**359**	**ECHO AP19**	59-59-30.4580S	087-00-01.0293W	**1000.02**	**359.00**
S60	W87	**2000**	1828.8	**359**	**ECHO AP20**	59-59-00.9160S	087-00-02.0581W	**2000.04**	**359.00**

4 CONCLUSIONS

The Visual Navigation Division (CG-NAV-1) requested that the Coast Guard RDC examine the performance of the AAPSilver software in calculating the geographic positions (latitude and longitude) of bearing and range offsets from reference locations.

Our conclusion based on the testing described above is that the AAPSilver software performs as would be expected. The agreement between results produced by AAPSilver and the reference software was within 8 cm in range, and agreed exactly in bearing. These differences may be compared to uncertainties associated with the use of Differential Global Positioning System receivers used to position Coast Guard ATON vessels and aids when the AAPSilver software is considered for distribution throughout the Coast Guard ATON fleet.

APPENDIX A. NATIONAL GEODETIC SURVEY FORWARD OUTPUT FOR BPP ALPHA

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : AP1
----------------
LAT =  41  0  0.00000 North
LON =  72  0  0.00000 West

Second Station : TP1
----------------
LAT =  41  0  2.56705 North
LON =  71 59 58.04370 West

Forward azimuth        FAZ =  30  0  0.0000 From North
Back azimuth           BAZ = 210  0  1.2835 From North
Ellipsoidal distance     S =        91.4400 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : AP1
----------------
LAT =  41  0  0.00000 North
LON =  72  0  0.00000 West

Second Station : TP2
----------------
LAT =  41  0  1.14499 North
LON =  71 59 57.48470 West

Forward azimuth        FAZ =  59  0  0.0000 From North
Back azimuth           BAZ = 239  0  1.6502 From North
Ellipsoidal distance     S =        68.5800 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088
First  Station : AP1
----------------
```

```
LAT =  41  0  0.00000 North
LON =  72  0  0.00000 West

Second Station : TP3
----------------
LAT =  40 59 59.39171 North
LON =  71 59 57.79404 West

Forward azimuth        FAZ = 110  0   0.0000 From North
Back azimuth           BAZ = 290  0   1.4472 From North
Ellipsoidal distance     S =        54.8640 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =   6378137.0000
Polar axis,         b   =   6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : AP1
----------------
LAT =  41  0  0.00000 North
LON =  72  0  0.00000 West

Second Station : TP4
----------------
LAT =  40 59 59.45429 North
LON =  71 59 59.69425 West

Forward azimuth        FAZ = 157  0   0.0000 From North
Back azimuth           BAZ = 337  0   0.2006 From North
Ellipsoidal distance     S =        18.2880 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =   6378137.0000
Polar axis,         b   =   6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : AP1
----------------
LAT =  41  0  0.00000 North
LON =  72  0  0.00000 West

Second Station : TP5
----------------
LAT =  40 59 57.42273 North
LON =  72  0  0.11879 West

Forward azimuth        FAZ = 182  0   0.0000 From North
Back azimuth           BAZ =   1 59 59.9221 From North
Ellipsoidal distance     S =        79.5528 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =   6378137.0000
Polar axis,         b   =   6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : AP1
----------------
LAT =  41  0  0.00000 North
LON =  72  0  0.00000 West

Second Station : TP6
----------------
LAT =  40 59 55.68868 North
LON =  72  0 10.26582 West

Forward azimuth        FAZ = 241  0  0.0000 From North
Back azimuth           BAZ =  60 59 53.2651 From North
Ellipsoidal distance     S =       274.3200 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =   6378137.0000
Polar axis,         b   =   6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : AP1
----------------
LAT =  41  0  0.00000 North
LON =  72  0  0.00000 West

Second Station : TP7
----------------
LAT =  41  0  7.71547 North
LON =  72  0 22.87627 West

Forward azimuth        FAZ = 294  0  0.0000 From North
Back azimuth           BAZ = 113 59 44.9915 From North
Ellipsoidal distance     S =       585.2160 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =   6378137.0000
Polar axis,         b   =   6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : AP1
----------------
LAT =  41  0  0.00000 North
LON =  72  0  0.00000 West

Second Station : TP8
```

```
-----------------
LAT =  41  0  0.88759 North
LON =  72  0  0.31392 West

Forward azimuth        FAZ = 345  0  0.0000 From North
Back azimuth           BAZ = 164 59 59.7940 From North
Ellipsoidal distance     S =        28.3464 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =   6378137.0000
Polar axis,         b   =   6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ALPHA
-----------------
LAT =  41  0  0.00000 North
LON =  72  0  0.00000 West

Second Station : ALPHA TP9
-----------------
LAT =  41  0 29.64180 North
LON =  72  0  0.00000 West

Forward azimuth        FAZ =   0  0  0.0000 From North
Back azimuth           BAZ = 180  0  0.0000 From North
Ellipsoidal distance     S =       914.4000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =   6378137.0000
Polar axis,         b   =   6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ALPHA
-----------------
LAT =  41  0  0.00000 North
LON =  72  0  0.00000 West

Second Station : ALPHA TP10
-----------------
LAT =  40 59 59.99816 North
LON =  71 59 20.87440 West

Forward azimuth        FAZ =  90  0  0.0000 From North
Back azimuth           BAZ = 270  0 25.6687 From North
Ellipsoidal distance     S =       914.4000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =   6378137.0000
Polar axis,         b   =   6356752.3141
```

```
Inverse flattening, 1/f =  298.25722210088

First  Station : ALPHA
----------------
LAT =  41  0  0.00000 North
LON =  72  0  0.00000 West

Second Station : ALPHA TP11
----------------
LAT =  40 59 30.35816 North
LON =  72  0  0.00000 West

Forward azimuth        FAZ = 180  0  0.0000 From North
Back azimuth           BAZ =   0  0  0.0000 From North
Ellipsoidal distance     S =       914.4000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ALPHA
----------------
LAT =  41  0  0.00000 North
LON =  72  0  0.00000 West

Second Station : ALPHA TP12
----------------
LAT =  40 59 59.99816 North
LON =  72  0 39.12560 West

Forward azimuth        FAZ = 270  0  0.0000 From North
Back azimuth           BAZ =  89 59 34.3313 From North
Ellipsoidal distance     S =       914.4000 m
```

Output from FORWARD

```
 Ellipsoid : GRS80 / WGS84  (NAD83)
 Equatorial axis,    a   =    6378137.0000
 Polar axis,         b   =    6356752.3141
 Inverse flattening, 1/f =  298.25722210088

First  Station : ALPHA
 ----------------
  LAT =  41  0  0.00000 North
  LON =  72  0  0.00000 West
Second Station : ALPHA TP13
 ----------------
  LAT =  41  0 29.64180 North
  LON =  72  0  0.00000 West

Forward azimuth        FAZ =   0  0  0.0000 From North
Back azimuth           BAZ = 180  0  0.0000 From North
Ellipsoidal distance     S =       914.4000 m
```

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APPENDIX B. NATIONAL GEODETIC SURVEY FORWARD OUTPUT FOR BPP BRAVO

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : BRAVO
 ----------------
  LAT =  13  0  0.00000 North
  LON = 144  0  0.00000 East

Second Station : AP1
 ----------------
  LAT =  13  0  2.57688 North
  LON = 144  0  1.51719 East

Forward azimuth        FAZ =  30  0  0.0000 From North
Back azimuth           BAZ = 210  0  0.3413 From North
Ellipsoidal distance     S =        91.4400 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : BRAVO
 ----------------
  LAT =  13  0  0.00000 North
  LON = 144  0  0.00000 East

Second Station : AP2
 ----------------
  LAT =  13  0  1.14938 North
  LON = 144  0  1.95073 East

Forward azimuth        FAZ =  59  0  0.0000 From North
Back azimuth           BAZ = 239  0  0.4388 From North
Ellipsoidal distance     S =        68.5800 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : BRAVO
```

```
 ----------------
   LAT =  13  0  0.00000 North
   LON = 144  0  0.00000 East

 Second Station : AP3
  ----------------
   LAT =  12 59 59.38938 North
   LON = 144  0  1.71083 East

 Forward azimuth        FAZ = 110  0  0.0000 From North
 Back azimuth           BAZ = 290  0  0.3849 From North
 Ellipsoidal distance     S =        54.8640 m
```

Output from FORWARD

```
 Ellipsoid : GRS80 / WGS84  (NAD83)
 Equatorial axis,    a   =   6378137.0000
 Polar axis,         b   =   6356752.3141
 Inverse flattening, 1/f =  298.25722210088

 First  Station : BRAVO
  ----------------
   LAT =  13  0  0.00000 North
   LON = 144  0  0.00000 East

 Second Station : AP4
  ----------------
   LAT =  12 59 59.45220 North
   LON = 144  0  0.23713 East

 Forward azimuth        FAZ = 157  0  0.0000 From North
 Back azimuth           BAZ = 337  0  0.0533 From North
 Ellipsoidal distance     S =        18.2880 m
```

Output from FORWARD

```
 Ellipsoid : GRS80 / WGS84  (NAD83)
 Equatorial axis,    a   =   6378137.0000
 Polar axis,         b   =   6356752.3141
 Inverse flattening, 1/f =  298.25722210088

 First  Station : BRAVO
  ----------------
   LAT =  13  0  0.00000 North
   LON = 144  0  0.00000 East

 Second Station : AP5
  ----------------
   LAT =  12 59 57.41287 North
   LON = 143 59 59.90787 East

 Forward azimuth        FAZ = 182  0  0.0000 From North
 Back azimuth           BAZ =   1 59 59.9793 From North
 Ellipsoidal distance     S =        79.5528 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : BRAVO
 ----------------
  LAT =  13  0  0.00000 North
  LON = 144  0  0.00000 East

Second Station : AP6
 ----------------
  LAT =  12 59 55.67227 North
  LON = 143 59 52.03825 East

Forward azimuth        FAZ = 241  0  0.0000 From North
Back azimuth           BAZ =  60 59 58.2091 From North
Ellipsoidal distance     S =       274.3200 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : BRAVO
 ----------------
  LAT =  13  0  0.00000 North
  LON = 144  0  0.00000 East

Second Station : AP7
 ----------------
  LAT =  13  0  7.74547 North
  LON = 143 59 42.25876 East

Forward azimuth        FAZ = 294  0  0.0000 From North
Back azimuth           BAZ = 113 59 56.0088 From North
Ellipsoidal distance     S =       585.2160 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : BRAVO
 ----------------
  LAT =  13  0  0.00000 North
  LON = 144  0  0.00000 East

Second Station : AP8
```

```
 ----------------
   LAT =  13  0  0.89098 North
   LON = 143 59 59.75654 East

 Forward azimuth        FAZ = 345  0  0.0000 From North
 Back azimuth           BAZ = 164 59 59.9452 From North
 Ellipsoidal distance     S =        28.3464 m
```

Output from FORWARD

```
 Ellipsoid : GRS80 / WGS84  (NAD83)
 Equatorial axis,    a   =    6378137.0000
 Polar axis,         b   =    6356752.3141
 Inverse flattening, 1/f =  298.25722210088

 First  Station : BRAVO
 ----------------
   LAT =  13  0  0.00000 North
   LON = 144  0  0.00000 East

 Second Station : BRAVO AP9
 ----------------
   LAT =  13  0 29.75526 North
   LON = 144  0  0.00000 East

 Forward azimuth        FAZ =   0  0  0.0000 From North
 Back azimuth           BAZ = 180  0  0.0000 From North
 Ellipsoidal distance     S =       914.4000 m
```

Output from FORWARD

```
 Ellipsoid : GRS80 / WGS84  (NAD83)
 Equatorial axis,    a   =    6378137.0000
 Polar axis,         b   =    6356752.3141
 Inverse flattening, 1/f =  298.25722210088

 First  Station : BRAVO
 ----------------
   LAT =  13  0  0.00000 North
   LON = 144  0  0.00000 East

 Second Station : BRAVO AP10
 ----------------
   LAT =  12 59 59.99951 North
   LON = 144  0 30.34380 East

 Forward azimuth        FAZ =  90  0  0.0000 From North
 Back azimuth           BAZ = 270  0  6.8259 From North
 Ellipsoidal distance     S =       914.4000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : BRAVO
 ----------------
  LAT =  13  0  0.00000 North
  LON = 144  0  0.00000 East

Second Station : BRAVO AP11
 ----------------
  LAT =  12 59 30.24472 North
  LON = 144  0  0.00000 East

Forward azimuth        FAZ = 180  0  0.0000 From North
Back azimuth           BAZ =   0  0  0.0000 From North
Ellipsoidal distance     S =       914.4000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : BRAVO
 ----------------
  LAT =  13  0  0.00000 North
  LON = 144  0  0.00000 East

Second Station : BRAVO AP12
 ----------------
  LAT =  12 59 59.99951 North
  LON = 143 59 29.65620 East

Forward azimuth        FAZ = 270  0  0.0000 From North
Back azimuth           BAZ =  89 59 53.1741 From North
Ellipsoidal distance     S =       914.4000 m
```

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APPENDIX C. NATIONAL GEODETIC SURVEY FORWARD OUTPUT FOR BPP CHARLIE

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : CHARLIE
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP1
 ----------------
  LAT =  59 59 57.44119 South
  LON =  86 59 57.05039 West

Forward azimuth        FAZ =  30  0  0.0000 From North
Back azimuth           BAZ = 209 59 57.4456 From North
Ellipsoidal distance     S =        91.4400 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : CHARLIE
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP2
 ----------------
  LAT =  59 59 58.85867 South
  LON =  86 59 56.20749 West

Forward azimuth        FAZ =  59  0  0.0000 From North
Back azimuth           BAZ = 238 59 56.7156 From North
Ellipsoidal distance     S =        68.5800 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : CHARLIE
```

```
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP3
 ----------------
  LAT =  60  0  0.60632 South
  LON =  86 59 56.67384 West

Forward azimuth        FAZ = 110  0  0.0000 From North
Back azimuth           BAZ = 289 59 57.1195 From North
Ellipsoidal distance     S =        54.8640 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : CHARLIE
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP4
 ----------------
  LAT =  60  0  0.54395 South
  LON =  86 59 59.53899 West

Forward azimuth        FAZ = 157  0  0.0000 From North
Back azimuth           BAZ = 336 59 59.6007 From North
Ellipsoidal distance     S =        18.2880 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : CHARLIE
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP5
 ----------------
  LAT =  60  0  2.56914 South
  LON =  87  0  0.17914 West

Forward azimuth        FAZ = 182  0  0.0000 From North
Back azimuth           BAZ =   2  0  0.1551 From North
Ellipsoidal distance     S =        79.5580 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : CHARLIE
 ----------------
  LAT =  60   0   0.00000 South
  LON =  87   0   0.00000 West

Second Station : AP6
 ----------------
  LAT =  60   0   4.29707 South
  LON =  87   0  15.47963 West

Forward azimuth        FAZ = 241   0   0.0000 From North
Back azimuth           BAZ =  61   0  13.4058 From North
Ellipsoidal distance     S =       274.3200 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : CHARLIE
 ----------------
  LAT =  60   0   0.00000 South
  LON =  87   0   0.00000 West

Second Station : AP7
 ----------------
  LAT =  59  59  52.30746 South
  LON =  87   0  34.48948 West

Forward azimuth        FAZ = 294   0   0.0000 From North
Back azimuth           BAZ = 114   0  29.8684 From North
Ellipsoidal distance     S =       585.2160 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : CHARLIE
 ----------------
  LAT =  60   0   0.00000 South
```

```
  LON =  87  0  0.00000 West

Second Station : AP8
 ----------------
  LAT =  59 59 59.11527 South
  LON =  87  0  0.47332 West

Forward azimuth        FAZ = 345  0  0.0000 From North
Back azimuth           BAZ = 165  0  0.4099 From North
Ellipsoidal distance     S =        28.3464 m
```

APPENDIX D. NATIONAL GEODETIC SURVEY FORWARD OUTPUT FOR BPP DELTA

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station :
 ----------------
  LAT =  10  0  0.00000 South
  LON = 170  0  0.00000 East

Second Station : DELTA AP1
 ----------------
  LAT =   9 59 57.42259 South
  LON = 170  0  1.50121 East

Forward azimuth        FAZ =  30  0  0.0000 From North
Back azimuth           BAZ = 209 59 59.7393 From North
Ellipsoidal distance     S =        91.4400 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station :
 ----------------
  LAT =  10  0  0.00000 South
  LON = 170  0  0.00000 East

Second Station : DELTA AP2
 ----------------
  LAT =   9 59 58.85038 South
  LON = 170  0  1.93018 East

Forward azimuth        FAZ =  59  0  0.0000 From North
Back azimuth           BAZ = 238 59 59.6648 From North
Ellipsoidal distance     S =        68.5800 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088
```

```
First  Station :
 ----------------
  LAT =  10  0  0.00000 South
  LON = 170  0  0.00000 East

Second Station : DELTA AP3
 ----------------
  LAT =  10  0  0.61074 South
  LON = 170  0  1.69282 East

Forward azimuth        FAZ = 110  0  0.0000 From North
Back azimuth           BAZ = 289 59 59.7060 From North
Ellipsoidal distance     S =        54.8640 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =   6378137.0000
Polar axis,         b   =   6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station :
 ----------------
  LAT =  10  0  0.00000 South
  LON = 170  0  0.00000 East

Second Station : DELTA AP4
 ----------------
  LAT =  10  0  0.54791 South
  LON = 170  0  0.23463 East

Forward azimuth        FAZ = 157  0  0.0000 From North
Back azimuth           BAZ = 336 59 59.9593 From North
Ellipsoidal distance     S =        18.2880 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =   6378137.0000
Polar axis,         b   =   6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station :
 ----------------
  LAT =  10  0  0.00000 South
  LON = 170  0  0.00000 East

Second Station : DELTA AP5
 ----------------
  LAT =  10  0  2.58766 South
  LON = 169 59 59.90884 East

Forward azimuth        FAZ = 182  0  0.0000 From North
Back azimuth           BAZ =   2  0  0.0158 From North
Ellipsoidal distance     S =        79.5528 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station :
 ----------------
  LAT =  10  0  0.00000 South
  LON = 170  0  0.00000 East

Second Station : DELTA AP6
 ----------------
  LAT =  10  0  4.32856 South
  LON = 169 59 52.12203 East

Forward azimuth        FAZ = 241  0  0.0000 From North
Back azimuth           BAZ =  61  0  1.3681 From North
Ellipsoidal distance     S =       274.3200 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station :
 ----------------
  LAT =  10  0  0.00000 South
  LON = 170  0  0.00000 East

Second Station : DELTA AP7
 ----------------
  LAT =   9 59 52.25264 South
  LON = 169 59 42.44586 East

Forward azimuth        FAZ = 294  0  0.0000 From North
Back azimuth           BAZ = 114  0  3.0479 From North
Ellipsoidal distance     S =       585.2160 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station :
 ----------------
  LAT =  10  0  0.00000 South
  LON = 170  0  0.00000 East
```

```
Second Station : DELTA AP8
 ----------------
  LAT =   9 59 59.10883 South
  LON = 169 59 59.75910 East

Forward azimuth        FAZ = 345  0  0.0000 From North
Back azimuth           BAZ = 165  0  0.0418 From North
Ellipsoidal distance     S =        28.3464 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : DELTA
 ----------------
  LAT =  10  0  0.00000 South
  LON = 170  0  0.00000 East

Second Station : AP9
 ----------------
  LAT =   9 59 30.23861 South
  LON = 170  0  0.00000 East

Forward azimuth        FAZ =   0  0  0.0000 From North
Back azimuth           BAZ = 180  0  0.0000 From North
Ellipsoidal distance     S =       914.4000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : DELTA
 ----------------
  LAT =  10  0  0.00000 South
  LON = 170  0  0.00000 East

Second Station : AP10
 ----------------
  LAT =   9 59 59.99962 South
  LON = 170  0 30.02425 East

Forward azimuth        FAZ =  90  0  0.0000 From North
Back azimuth           BAZ = 269 59 54.7863 From North
Ellipsoidal distance     S =       914.4000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : DELTA
 ----------------
  LAT =  10  0  0.00000 South
  LON = 170  0  0.00000 East

Second Station : AP11
 ----------------
  LAT =  10  0 29.76138 South
  LON = 170  0  0.00000 East

Forward azimuth        FAZ = 180  0  0.0000 From North
Back azimuth           BAZ =   0  0  0.0000 From North
Ellipsoidal distance     S =       914.4000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : DELTA
 ----------------
  LAT =  10  0  0.00000 South
  LON = 170  0  0.00000 East

Second Station : AP12
 ----------------
  LAT =   9 59 59.99962 South
  LON = 169 59 29.97575 East

Forward azimuth        FAZ = 270  0  0.0000 From North
Back azimuth           BAZ =  90  0  5.2137 From North
Ellipsoidal distance     S =       914.4000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : DELTA
 ----------------
  LAT =  10  0  0.00000 South
  LON = 170  0  0.00000 East
```

```
Second Station : AP13
 ----------------
  LAT =   9 59 30.23861 South
  LON = 170  0  0.00000 East

Forward azimuth        FAZ =   0  0  0.0000 From North
Back azimuth           BAZ = 180  0  0.0000 From North
Ellipsoidal distance     S =       914.4000 m
```

APPENDIX E. NATIONAL GEODETIC SURVEY FORWARD OUTPUT FOR BPP ECHO

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP1
 ----------------
  LAT =  59 59 59.99996 South
  LON =  86 59 54.10065 West

Forward azimuth        FAZ =  90  0  0.0000 From North
Back azimuth           BAZ = 269 59 54.8910 From North
Ellipsoidal distance     S =        91.4400 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP2
 ----------------
  LAT =  59 59 59.99909 South
  LON =  86 59 30.50323 West

Forward azimuth        FAZ =  90  0  0.0000 From North
Back azimuth           BAZ = 269 59 34.4550 From North
Ellipsoidal distance     S =       457.2000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
```

```
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP3
 ----------------
  LAT =  59 59 59.99634 South
  LON =  86 59  1.00645 West

Forward azimuth        FAZ =  90  0  0.0000 From North
Back azimuth           BAZ = 269 59  8.9101 From North
Ellipsoidal distance     S =       914.4000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =   6378137.0000
Polar axis,         b   =   6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP4
 ----------------
  LAT =  59 59 59.98536 South
  LON =  86 58  2.01292 West

Forward azimuth        FAZ =  90  0  0.0000 From North
Back azimuth           BAZ = 269 58 17.8202 From North
Ellipsoidal distance     S =      1828.8000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =   6378137.0000
Polar axis,         b   =   6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP5
 ----------------
  LAT =  60  0  2.95465 South
  LON =  87  0  0.00000 West

Forward azimuth        FAZ = 180  0  0.0000 From North
Back azimuth           BAZ =   0  0  0.0000 From North
Ellipsoidal distance     S =        91.4400 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP6
 ----------------
  LAT =  60  0 14.77323 South
  LON =  87  0  0.00000 West

Forward azimuth        FAZ = 180  0  0.0000 From North
Back azimuth           BAZ =   0  0  0.0000 From North
Ellipsoidal distance     S =       457.2000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP7
 ----------------
  LAT =  60  0 29.54645 South
  LON =  87  0  0.00000 West

Forward azimuth        FAZ = 180  0  0.0000 From North
Back azimuth           BAZ =   0  0  0.0000 From North
Ellipsoidal distance     S =       914.4000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP8
```

```
 ----------------
   LAT =  60   0 59.09287 South
   LON =  87   0  0.00000 West

 Forward azimuth        FAZ = 180   0   0.0000 From North
 Back azimuth           BAZ =   0   0   0.0000 From North
 Ellipsoidal distance     S =      1828.8000 m
```

Output from FORWARD

```
 Ellipsoid : GRS80 / WGS84  (NAD83)
 Equatorial axis,    a   =    6378137.0000
 Polar axis,         b   =    6356752.3141
 Inverse flattening, 1/f =  298.25722210088

 First  Station : ECHO
 ----------------
   LAT =  60   0  0.00000 South
   LON =  87   0  0.00000 West

 Second Station : AP9
 ----------------
   LAT =  59 59 59.99996 South
   LON =  87   0  5.89935 West

 Forward azimuth        FAZ = 270   0   0.0000 From North
 Back azimuth           BAZ =  90   0   5.1090 From North
 Ellipsoidal distance     S =        91.4400 m
```

Output from FORWARD

```
 Ellipsoid : GRS80 / WGS84  (NAD83)
 Equatorial axis,    a   =    6378137.0000
 Polar axis,         b   =    6356752.3141
 Inverse flattening, 1/f =  298.25722210088

 First  Station : ECHO
 ----------------
   LAT =  60   0  0.00000 South
   LON =  87   0  0.00000 West

 Second Station : AP10
 ----------------
   LAT =  59 59 59.99909 South
   LON =  87   0 29.49677 West

 Forward azimuth        FAZ = 270   0   0.0000 From North
 Back azimuth           BAZ =  90   0  25.5450 From North
 Ellipsoidal distance     S =       457.2000 m
```

Output from FORWARD

```
 Ellipsoid : GRS80 / WGS84  (NAD83)
 Equatorial axis,    a   =    6378137.0000
 Polar axis,         b   =    6356752.3141
```

```
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP11
 ----------------
  LAT =  59 59 59.99634 South
  LON =  87  0 58.99355 West

Forward azimuth        FAZ = 270  0  0.0000 From North
Back azimuth           BAZ =  90  0 51.0899 From North
Ellipsoidal distance     S =       914.4000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =   6378137.0000
Polar axis,         b   =   6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP12
 ----------------
  LAT =  59 59 59.98536 South
  LON =  87  1 57.98708 West

Forward azimuth        FAZ = 270  0  0.0000 From North
Back azimuth           BAZ =  90  1 42.1798 From North
Ellipsoidal distance     S =      1828.8000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =   6378137.0000
Polar axis,         b   =   6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP13
 ----------------
  LAT =  59 59 57.04535 South
  LON =  87  0  0.00000 West

Forward azimuth        FAZ =   0  0  0.0000 From North
Back azimuth           BAZ = 180  0  0.0000 From North
```

```
Ellipsoidal distance     S =        91.4400 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP14
 ----------------
  LAT =  59 59 45.22676 South
  LON =  87  0  0.00000 West

Forward azimuth        FAZ =   0  0  0.0000 From North
Back azimuth           BAZ = 180  0  0.0000 From North
Ellipsoidal distance     S =       457.2000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP15
 ----------------
  LAT =  59 59 30.45351 South
  LON =  87  0  0.00000 West

Forward azimuth        FAZ =   0  0  0.0000 From North
Back azimuth           BAZ = 180  0  0.0000 From North
Ellipsoidal distance     S =       914.4000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West
```

```
Second Station : AP16
 ----------------
  LAT =  59 59  0.90698 South
  LON =  87  0  0.00000 West

Forward azimuth        FAZ =   0  0  0.0000 From North
Back azimuth           BAZ = 180  0  0.0000 From North
Ellipsoidal distance     S =      1828.8000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP17
 ----------------
  LAT =  59 59 57.04580 South
  LON =  87  0  0.10296 West

Forward azimuth        FAZ = 359  0  0.0000 From North
Back azimuth           BAZ = 179  0  0.0892 From North
Ellipsoidal distance     S =        91.4400 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP18
 ----------------
  LAT =  59 59 45.22901 South
  LON =  87  0  0.51473 West

Forward azimuth        FAZ = 359  0  0.0000 From North
Back azimuth           BAZ = 179  0  0.4458 From North
Ellipsoidal distance     S =       457.2000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP19
 ----------------
  LAT =  59 59 30.45801 South
  LON =  87  0  1.02932 West

Forward azimuth        FAZ = 359  0  0.0000 From North
Back azimuth           BAZ = 179  0  0.8914 From North
Ellipsoidal distance     S =       914.4000 m
```

Output from FORWARD

```
Ellipsoid : GRS80 / WGS84  (NAD83)
Equatorial axis,    a   =    6378137.0000
Polar axis,         b   =    6356752.3141
Inverse flattening, 1/f =  298.25722210088

First  Station : ECHO
 ----------------
  LAT =  60  0  0.00000 South
  LON =  87  0  0.00000 West

Second Station : AP20
 ----------------
  LAT =  59 59  0.91598 South
  LON =  87  0  2.05814 West

Forward azimuth        FAZ = 359  0  0.0000 From North
Back azimuth           BAZ = 179  0  1.7823 From North
Ellipsoidal distance     S =      1828.8000 m
```